VOLUME 80 SEPARATE No. 561

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

DECEMBER, 1954

FOUNDATION FAILURES IN RESIDENCES AND SMALL STRUCTURES

by Karl V. Taylor, M. ASCE

STRUCTURAL DIVISION

(Discussion open until April 1, 1955)

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

FOUNDATION FAILURES IN RESIDENCES AND SMALL STRUCTURES

Karl V. Taylor,[1] M. ASCE

As most of us are aware, the problems associated with the design of foundations for residences and light structures have been dramatically highlighted by the enormous and widespread damage caused by settlement during the past two years (1952-1953) of serious drouth. In the greater Kansas City area alone it has been estimated that settlement caused by lowering of the ground water table has resulted in structural damage to perhaps as many as 65% of the homes. The average cost of repairs varies from about $600 to $3,000 per unit which adds up to a real or potential repair bill in the order of $20,000,000 to $40,000,000 for the home owners in just this one locality. Multiply that figure by the number of similarly affected areas throughout the United States and we immediately realize we are not dealing with a minor annoyance. This type of settlement, in contrast to some others which I shall mention later, is not necessarily due to a lack of observance on the part of the architect or contractor of what has normally been considered good construction practice. Both newly constructed and older buildings suffer the same type of damage, so we must look first at the basic causes of such settlement before suggesting remedial measures which would be applicable to some cases.

Simply stated, building settlements associated with drouth conditions are merely the result of inordinate shrinkage of the foundation subsoils. However, some of the implications and ramifications of this statement are not so simple.

In a broad sense the normal ground water table will have roughly the same general type of configuration as the ground surface with the contours smoothed out considerably. Generally under the higher knolls the zone of high moisture content will be deeper and in valleys nearer the surface and will coincide with the surface at springs and usually at flowing streams. During periods of prolonged drouth however, the rate of evaporation from the surface exceeds the recharge, the water table drops and the contours tend to smooth out more and more. Thus in the general sense the drop of the water table on the knolls and ridges will tend to be much greater than in the valleys. Therefore, settlement associated with lowering of the ground water table will often appear first in those buildings located on higher ground.

As all of you know, not all soils undergo large volume changes with a decrease in moisture content. It might be of interest to discuss briefly the mechanics of shrinkage and swell so that the presence of sensitive soil types may be more easily detected in the field. Shrinkage characteristics of soil are intimately related to soil structure and particle size. In a sandy soil

[1] Chief, Foundation and Materials Branch, Kansas City District, Corps of Engineers, Kansas City, Mo.

the grains are in direct, stable contact with each other, the soil structure is rigid and while the voids between grains are large the volume of voids is comparatively low. These properties permit little compressibility of the sand mass even under heavy loads. Conversely, clay soils are compressible because the fine particles during deposition tend to arrange themselves in a much more open, cellular or honeycomb type of structure. Although the sizes of the voids in clay are very small the total volume of voids with respect to the volume of the clay mass is large. As a crude analogy we might visualize the difference in structure and compressibility between sand and clay as somewhat like that between a box full of marbles and one full of sponges. The behavior of clay is strongly influenced by the fact that a high percentage of particles are colloidal. These particles are usually smaller than about one micron and have an extremely high ratio of surface area to mass or volume, particularly since most clay particles are plate or rod shaped. Surface energy rather than mass energy controls the actions of such particles and as a result their behavior in a suspension of soil in water or in a soil mass is very different from that usually associated with larger size particles. Each colloidal particle is surrounded by a film of adsorbed water (in the order of perhaps 100 molecules in thickness) which is so strongly bound to the soil particle by electrical attraction that it no longer behaves as normal water but more like a semi-solid or viscous substance. The remaining water in the soil voids which is not partially or completely immobilized by attractive forces is pore water and behaves in accord with normal hydrodynamic laws. In a saturated sand nearly all the water is pore water while in a saturated clay a large percentage (perhaps 1/4 to 1/2) of the water is adsorbed.

When these fine soil particles are close together very strong attractive forces exist between them. These bonds or linkages are complex electrochemical phenomena which in the aggregate are manifest as soil cohesion. Water, being a polar liquid, plays the predominant role in establishing these powerful bonds and linkages between the very fine soil particles. The attraction forces increase greatly for small changes in distance between closely spaced soil particles and this spacing is influenced by the thickness of the absorbed water films.

Now let us consider what happens when a saturated clay soil is subjected to drying by surface evaporation. As the wet soil loses water the decrease in soil volume is equal to the volume of water removed and a plot of soil volume versus water content would be a straight line. The force causing compression of the soil is the tensile force in the water contained in the soil voids due to the formation of menisci at the air-water boundaries existing either within the soil mass or at its surface. This force is inversely proportional to the diameter of the so called capillary tubes formed by interconnecting voids between grains and may become a very large compressive force in fine grained clays. For example, it can be demonstrated that if the average diameter of voids in a clay mass was about .2 micron the compressive force applied to the drying soil would probably exceed 15 tons per square foot. The formation of menisci at the air water boundaries causes the capillary rise in soils with which we are all familiar. Above the surface of the true water table there exists a zone of varying depth depending on the size of soil voids in which almost complete saturation exists. Above this there are fringe zones of varying degrees of saturation. Since the height of capillary rise, like the compressive force just mentioned, is inversely proportional to the size of the soil voids these fringe zones are the inevitable result of the

random arrangement of voids of widely varying size found in all soils. Obviously, since the average diameter of voids in sand is much greater than in clay the height of capillary rise would be much less than in the clay.

As dehydration progresses a point is reached at which the change in soil volume becomes very much less than the volume of water removed. The water content at this state is commonly designated as the shrinkage limit. At the shrinkage limit the soil changes color due to the retreat of the air-water boundary within the soil mass and the invasion of air in the surface soil voids. As evaporation continues shrinkage also continues at a decreasing rate until a state of equilibrium is established in the soil voids, which depends upon the vapor pressure of the water and the relative humidity.

During the shrinkage process the soil mass undergoes important changes. In fine grained soils the large compressive forces generated by the tension in the water rearrange the soil particles into a more compact mass, the adsorbed water films are decreased in thickness and the cohesive forces between soil particles are tremendously increased. This accounts for the high strength of dried clay. On the other hand, the effects of drying on a sand mass are quite different. The relatively rigid soil skeleton is far less subject to volume change under pressure, the capillary forces producing the compression are weak because of the large size of voids, and since adsorbed water is only a minor part of the whole water content, the effects of thinning these films is relatively inconsequential. For soils with gradations intermediate between those of pure clay and clean sand the behavior characteristics on drying will be influenced strongly by the finer 10 or 20 percent of the particles.

If a thoroughly desiccated clay is rewetted, some swelling will take place. However, with certain notable exceptions most soils will not swell back to their original volume prior to desiccation. The shrinkage forces rearranged the soil particles into a denser mass and increased the cohesion between particles. However, no forces exist which would cause a general rearrangement of soil particles and restore the open cellular structure which the compressible soil had originally. Consequently, the volume change during swell is usually much less than that occurring from shrinkage by thorough drying. As the soil is rewetted the compressive forces in the soil mass induced by capillarity are gradually released allowing the soil to regain some of the "elastic" portion of the compression developed during drying. It is believed that this portion of the compression is attributable to distortion of those flat, flake-like particles which form a substantial part of most clays. In addition, a relatively small but very important part of the swell is caused by the thickening of the water films and the forcing apart of the soil grains. The forces associated directly with the thickening of the water films are powerful and a tightly confined soil can generate tremendous pressures in this phase of the swelling process. The part of the swell occasioned by elastic recovery in the soil skeleton, while larger than that part just mentioned, is generally capable of generating relatively weaker forces so that if external loads are applied or remain on a desiccated soil some of this portion of the shrinkage will be permanent. The exceptional soils mentioned previously are those containing a significant percentage of montmorillonite, a clay mineral commonly found widely distributed in many areas largely in the western third of the United States. This mineral undergoes large volume changes on both drying and rewetting and correspondingly influences the clays of which it is a part.

Since we are interested only in the settlement problems, this brief discussion of the mechanics of shrinkage and swell brings out the following

points of interest from a structural point of view:

(1) The soils which generally are subject to serious shrinkage on drying are those plastic, colloidal clays which have an open cellular structure or high volume of voids.

This does not mean, however, that large shrinkages are characteristic of only these soils. Lean clays, organic clays and some types of fine silts shrink very appreciably on drying. Laboratory testing adequate to determine quantitatively the amount of settlement to be expected from soil shrinkage generally would be much too expensive to be applicable to residence and small building foundations.

The owner of a proposed new multi-million dollar plant building would consider it only good business to invest a very considerable sum of money in investigation of foundation conditions as an assurance of the adequacy of the foundation design and a guarantee against expensive settlement damage from any cause. It is certainly just as important, or even more important to the individual home owner to have that same assurance. Every builder has an obligation to his client to at least take a few borings at the site, estimate the potentialities for trouble by a few very simple field tests and take some reasonable precautions in the design of the substructure to avoid expensive repairs in the future.

(2) Shrinkage progresses from the surface downward under severe drying through evaporation.

The foundations of porches, sometimes those of chimneys and often wings of houses are located a number of feet higher in elevation than those of the main portions of the house with the basement under it. As drying progresses downward the soil beneath the shallower footings shrinks long before the zone of desiccation has penetrated deeply enough to affect the deeper main footings. Consequently the porch settles and pulls away from the house, the chimney on the shallow footing begins to lean outward and crack away from the building and serious cracking shows up where the wings and main building join. Obviously, if the drying goes deeply enough the footings below basement floor level will begin to settle also. However, the differential settlement will remain or even grow somewhat more pronounced since the settlement of any particular footing is a function of the total thickness of soil beneath that footing which is affected by shrinkage. The answer to this phase of the problem is simply this: when the foundation soil is a type adjudged to be sensitive to moisture changes, construct all exterior footings so that their bases will be about the same depth below the finished ground surface. This will tend to minimize settlement damage, but as I shall point out presently, it will not eliminate all differential settlement due to shrinkage.

The next logical question is what depth would ordinarily be considered adequate for exterior footing of houses. It is of course standard construction practice to place footings below the zone of frost penetration and normal seasonal moisture change. How much additional penetration below this minimum depth should be used to combat settlement during exceptionally dry seasons is merely a matter of economics. The purchase of this additional insurance against this type of settlement is like buying any other kind of insurance: It depends upon the owner's circumstances and his individual inclinations. As the owner's agent the architect must consider these factors in the foundation design.

Where only lightly loaded residence or industrial building footings are involved, placing them at greater than ordinary depth can be economically

accomplished, for example, by drilling 12" to 18" diameter holes to the desired depth by earth auger equipment and backfilling the holes with concrete to form short piles or columns for carrying the structure rather than shallow continuous footings. As you know, this method has been used with marked success in underpinning operations for some years.

(3) The compressive stresses developed in the drying foundation soil can, in the case of sensitive clays, greatly exceed man-made loads usually imposed by the light structures with which we are presently concerned.

This statement indicates that the relatively minor adjustments which can be made in unit bearing pressure for light footings will have no influence whatever on settlement caused by desiccation.

(4) After drying has progressed to the point where the soil structure has undergone important changes swelling associated with rewetting will usually be much smaller than the volume change during compression, particularly if the soil carries a substantial superimposed load.

However, it should be remembered that a part of such swelling that does occur will exert powerful forces if the soil is confined. This point is brought out in answer to the question of what will happen to those houses which have settled and have undergone foundation repairs while the subsoil is still very dry. As the soil regains moisture commensurate with the greater density it has acquired, some swell is very apt to occur and cause some upward movement of the foundation. The amount of movement will vary widely with different soils and will depend somewhat on their prior history, but for most soils in this area it is believed the movement will be relatively much smaller than the compression.

In this connection it might be noted that normal seasonal changes cause some cyclic shrinkage and swell and lightly loaded building foundations will rise and fall with these changes. Many of us have a pet door or window that sticks in the rainy season but works fine in dry weather. This could reflect those slight foundation movements, together with the shrinkage or swell of the framing of the house. In some sections of the country, particularly in the southwest, these seasonal changes are reported to cause very substantial fluctuations in the ground surface.

(5) Since shrinkage is a function of the relative rates of evaporation and recharge, the factors which influence the rate of evaporation within a small area have an important bearing on the differential settlement developed in a structure.

Footings located in areas where evaporation of ground water from an exposed surface can take place readily will settle sooner and usually more than footings in some sheltered areas. Exterior footings, particularly those at corners of houses, where adjacent soil surfaces are exposed, settle more and sooner than interior footings where the soil surfaces are more protected or even covered by a concrete basement floor. The flat slab type of house foundation built at or just below the ground surface is quite susceptible to distortions from this cause. Evaporation takes place much more readily around the periphery of the slab than under the interior portions with the result that cracks and convex upward distortions are apt to occur. If evaporation could be retarded for some distance (say 25') around the slab or footing settlement would also be retarded though not prevented, since in time the ground water would migrate to the outer drier soil. Following this line of reasoning it could be assumed that a sand blanket placed just below the topsoil to suppress partially the capillary rise might serve to retard drying.

The effects of this type of differential settlement are also particularly noticeable in basement walls constructed of concrete blocks or native stone. Lightly reinforced monolithic concrete basement walls, through better beam action, would tend to reduce differential settlement in many cases.

In connection with differential shrinkage it would be appropriate to mention here the cracking of basement walls and floors that has sometimes been observed in the vicinity of a heating plant. The higher temperature level accelerates the evaporation of ground water through the pores in the concrete and causes local shrinkage of the soil and differential settlement. If an asphaltic coating were applied to the soil surface prior to placing the concrete, this moisture loss could largely be prevented.

To this point little has been said about measures which would be economically feasible for the prevention of shrinkage settlements of houses already constructed on sensitive clays, for the very good reason that apparently no such generally applicable measures have as yet been developed. Repair of the damage after it has occurred is probably no more expensive than the structural revisions to the foundation which would have been required to prevent it. Repairs usually consist of underpinning the foundation by one of several widely used methods, then jacking the house back into alignment or simply shimming under the sills as required.

While the type of settlement we have been discussing is so widespread at present as to cause much concern, it actually is of very infrequent occurrence compared with some other types which occur constantly as individual cases. I should like to review briefly some of the more common examples.

Settlements caused directly or indirectly by building on fill have long been a common, though frequently misunderstood phenomenon. They are of two general types. The first and most obvious cause of such settlements is placing footings on loose, poorly compacted material. In this instance the quality of the fill itself is at fault. Actually, there are no major problems which may be considered unique to construction of load bearing fills. The causes of failure of such fills are not inherent, but are the result of gross violation of sound, well established fundamental principles of soil mechanics. Information relative to pertinent theory and recommended practice is abundantly available in published literature and will not be reviewed here. In short, it is not construction on fill which must be avoided but instead it is the all-too-common faulty construction practices in placing fill which need correction.

One less obvious type of failure of frequent occurrence associated with placement of structures on fill is sometimes erroneously blamed on poor quality of fill or non-uniform compaction. Often structures must be placed partly in cut and partly on fill. In the cut portion a part of the stress in the original foundation soil is relieved by removal of overburden and may in effect be subtracted from that induced by the building load. Consequently, the movement in this portion of the foundation is largely a function of the difference between the load removed and that restored by the structure. In the fill portion of the foundation the situation is reversed. The load causing compression of the original ground is the sum of the building load and the weight of the new fill. Due to time effects in the consolidation of soils such compressions can continue for some time after the fill and building loads are applied. The settlement of footings placed near the surface of the fill will reflect the compression in both the fill and underlying original ground. The

differential settlement of the structure will then be a function of these two opposite effects, and obviously the total differential could be large regardless of the excellence of the new fill. Industrial buildings covering considerable areas of "made" sites frequently show distressing differential settlements from this cause, but, because of the small area covered, residences are much less likely to suffer such differential settlement although the total settlement, if the building is on the fill portion, may be large.

Foundations designed to preclude this kind of settlement can be very expensive and are usually not feasible for residence or light industrial buildings. Time, if available, is the cheapest remedy. If the new fill can be placed far enough in advance of building construction to partially consolidate the original ground only a fraction of the total movement will show up as building settlement. Each situation is unique and a combination of many factors must be considered. For instance, if the original ground was soft clay settlement or consolidation may continue for many years, whereas a relatively shallow depth of silt may consolidate rapidly enough to make a delay in building well worth while. Sometimes the consolidation of the original soil can be speeded up by placing a layer of sand on the surface before the new fill is placed, and thus act as an underdrain.

While I am on the subject of "cut and fill" foundations, I should like to relate an experience which may be of interest. Some two years ago I was asked to examine and determine the cause of some very serious cracking in the brick walls and concrete floors of a two-story plant building in this area. Repeated careful surveys revealed considerable differential movement, but the fact that the movements all appeared to be in the upward direction was blamed on a supposedly faulty bench mark. A detailed investigation of the foundation, however, definitely established that the movements were in reality upward. The culprit in this case was a swelling shale at the base of the footings. The swelling was due to a combination of factors, of which saturation under relatively light loads appeared to be dominant. This example is cited to illustrate the fact that so-called settlements are not always what they appear to be, and it sometimes requires a little research to disclose the true situation.

One other example of difficulties associated with fills--(and I have observed many instances of this) --might be appropriate here. In industrial building construction, as you know, a considerable excavation is often necessary around the periphery of the building to permit construction of the outer footings and grade beams. The backfill in this excavation and the undisturbed material within the building area are brought to grade to form the foundation for the floor slab. If that backfill operation was not very carefully done, cracks in the floor slab, paralleling the walls, are almost inevitable. A loose, heterogeneous backfill will shrink or compress under load and permit undue deflection of the slab adjacent to the walls. Conversely, an over-zealous contractor might ram an expansive clay into the hole so tightly that if the moisture content increases, as it might with evaporation inhibited by the concrete slab, swelling of the soil and cracking of the concrete will also result. In some other instance perhaps it was more expedient to use sand backfill when the natural undisturbed material was clay. The result -- cracking of the floor slab -- because of the different degree of support offered by the two materials. Obviously, the ideal condition would be to have all portions of the floor uniformly supported on materials which will yield just enough to equalize the floor and main building settlements.

While site conditions will rarely permit achievement of this ideal, sufficient soil studies are warranted on large projects to develop a reasonable approach to it. For the smaller projects and light construction with which we are presently concerned probably the best practice is to backfill such excavations with material similar to that present under the remainder of the floor slab, but uniformly compacted to a density, as nearly as can be judged, equal to that of the adjacent undisturbed material.

Commonly, settlement problems arise from or are associated with construction on soils which are sufficiently soft to yield or compress appreciably under the applied load. Residence bearing loads are usually quite low so that for most soils they are not critical. It occasionally happens, though, that a house on a questionable foundation soil will show no signs of distress until another and perhaps much heavier structure is built adjacent to it. Compression of the subsoil caused by the new structure spreads laterally under the old, resulting in differential settlement and tipping toward the new structure.

Instances are not infrequent when hillside building sites, often covering a large area, will slowly creep downhill. The causes are varied and can be established for each case only after thorough study. However, one of the most prevalent causes is lack of drainage, faulty layout of the drainage system or improper design of the drains themselves. I should like to digress for a moment from settlement problems and discuss very briefly the design of those drains. In spite of widely published information on the subject, I note that the old practice of using extremely coarse crushed stone or gravel in French drains or as pervious backfill around pipe drains is still being followed to some extent. Eventual failure of such drains is inevitable if the adjacent material is fine sand or silt because it will infiltrate the coarse material and very effectively plug the voids. If the ratio of the 15% size of the filter material to the 85% size of the foundation material is 5 or less, infiltration will not be appreciable, or if the ratio of the 85% size of the filter to the size of the holes in the pipe drains is greater than 1.0 for round holes or 1.2 for square holes, loss of material into the pipe will not be serious. In order to be a good filter the ratio of the 15% size of filter material to the 15% size of foundation material should be greater than 5. If no soil gradation data are available backfill the drains with clean coarse sand similar to a good concrete sand, rather than use coarse stone or gravel.

All this discussion has dealt with settlement situations in which the loads imposed by the structure in question have had very little if any influence on the magnitude of that settlement. The broad and very important category of foundation problems in which the weight of the structure is the dominant factor has not been reviewed at all. Such problems are almost always associated with monumental buildings, massive industrial structures, dams, etc., and are beyond the scope of our present discussion of residences and light industrial buildings. It is hoped that our discussion today will further in some measure an awareness of soil science in practical "everyday" foundation construction by those who are by necessity associated with, but have no cogent reason to be specialists in the field of soil mechanics. Such "soil consciousness" will pay dividends to John Q. Public in reduced maintenance on the home which may represent the principal investment of his lifetime.

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

VOLUME 79 (1953)

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

---

c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1955

PRESIDENT
WILLIAM ROY GLIDDEN

VICE-PRESIDENTS

Term expires October, 1955:
ENOCH R. NEEDLES
MASON G. LOCKWOOD

Term expires October, 1956:
FRANK L. WEAVER
LOUIS R. HOWSON

DIRECTORS

Term expires October, 1955:
CHARLES B. MOLINEAUX
MERCEL J. SHELTON
A. A. K. BOOTH
CARL G. PAULSEN
LLOYD D. KNAPP
GLENN W. HOLCOMB
FRANCIS M. DAWSON

Term expires October, 1956:
WILLIAM S. LaLONDE, JR.
OLIVER W. HARTWELL
THOMAS C. SHEDD
SAMUEL B. MORRIS
ERNEST W. CARLTON
RAYMOND F. DAWSON

Term expires October, 1957:
JEWELL M. GARRELTS
FREDERICK H. PAULSON
GEORGE S. RICHARDSON
DON M. CORBETT
GRAHAM P. WILLOUGHBY
LAWRENCE A. ELSENER

PAST-PRESIDENTS
Members of the Board

WALTER L. HUBER
DANIEL V. TERRELL

EXECUTIVE SECRETARY
WILLIAM N. CAREY

TREASURER
CHARLES E. TROUT

ASSISTANT SECRETARY
E. L. CHANDLER

ASSISTANT TREASURER
CARLTON S. PROCTOR

PROCEEDINGS OF THE SOCIETY

HAROLD T. LARSEN
Manager of Technical Publications

DEFOREST A. MATTESON, JR.
Editor of Technical Publications

PAUL A. PARISI
Assoc. Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

SAMUEL B. MORRIS, *Chairman*

JEWELL M. GARRELTS, *Vice-Chairman*

GLENN W. HOLCOMB
OLIVER W. HARTWELL
ERNEST W. CARLTON
DON M. CORBETT